MSFC-506-Abstract

Middleware Trade Study for NASA Domain

Abstract

This presentation presents preliminary results of a trade study designed to assess three distributed simulation middleware technologies for support of the NASA Constellation Distributed Space Exploration Simulation (DSES) project and Test and Verification Distributed System Integration Laboratory (DSIL). The technologies are: the High Level Architecture (HLA), the Test and Training Enabling Architecture (TENA), and an XML-based variant of Distributed Interactive Simulation (DIS-XML) coupled with the Extensible Messaging and Presence Protocol (XMPP). According to the criteria and weights determined in this study, HLA scores better than the other two for DSES as well as the DSIL.

MSFC-SDC-Presentation

Middleware Trade Study for NASA Domain

Dan Bowman

Teledyne Brown Engineering

Huntsville, Alabama

September 19, 2007

Agenda

- Study Team
- Study Purpose and Scope
- Candidate Descriptions
- Summary
- Method
- Evaluation Criteria
- Criteria Weighting
- Raw Scores
- Weighted Grades

Study Team

- **Zack Crues, JSC, DSES Lead – Study POC**
- **David Hasan, L3 Communications – Study Lead**
- Robert Horton, L3 Communications
- Dan Bowman, Teledyne Brown Engineering
- Dannie Cutts, Aegis Technologies
- Danny Thomas, Aegis Technologies
- Bobby Hartway, Aegis Technologies
- Nancy Fisher, Teledyne Brown Engineering

Study Purpose and Scope

- **Study Purpose**
  - Answer the question:
    - **Which of three candidate middleware technologies is best in Distributed Simulation Exploration Simulation (DSES) and Distributed System Integration Laboratory (DSIL)?**
      - High Level Architecture (HLA)
      - Test and Training Enabling Architecture (TENA)
      - XML-based version of the Distributed Interactive Simulation (DIS) (using Extensible Messaging and Presence Protocol (XMPP) as messaging protocol)

- **Study Scope**
  - Evaluated relative merits of the candidates against each other
  - Did not address:
    - **General architecture questions (e.g., for DSIL, geographical distribution of time sensitive components)**
    - **Other (e.g., custom development of a distributed middleware)**

Candidate Descriptions

- **HLA**
  - Originated with DoD as a standard set of services for linking distributed simulations and training applications; now IEEE standard (1516) with commercially available Run-Time Infrastructure (RTI) implementations
  - Does not specify on-the-wire data representations
  - Specifies a set of rules that "federates" must obey to form a "federation" and set of services (with C++ and Java mappings) through which the federate simulations interact with each other and the RTI
- **TENA**
  - Originated with DoD; designed to support interoperability and reuse among DoD test and training ranges
  - Provides object-oriented approach for real-time exchange of data and invocation of remotely located objects
  - DoD Central Test and Evaluation Program (CTEIP) sponsors TENA middleware development and distributes the only implementation
- **DIS-XML/XMPP**
  - Originated with DoD; defines on-the-wire protocol now adopted as IEEE standard 1278
  - DIS-XML utilizes Extensible Markup Language (XML) to encode DIS data on the wire to take advantage of wide availability of XML-processing tools and standardization
  - Jabber/XMPP chat room concept (though not explicitly intended for distributed simulation) can be effectively used as a communications mechanism for distributed simulations

Summary

This briefing provides a summary of NASA Constellation DSES/DSIL Distributed Simulation Middleware Trade Study, June 2007.

- Conclusions
  - **DIS-XML/XMPP falls far short of what we need for DSES and DSIL,**
  - **HLA is the best solution for DSES and**
  - **Even in the DSIL, HLA comes out ahead.**
- Caveats
  - Criteria weights and some raw scores derived from subjective judgments of the Study Team
    - **Data and weights are available for review**
  - **Plan to complete benchmark codes as standardized test suite**
    - **Results of the study not sufficiently sensitive to latency and throughput scores for the benchmark results to affect conclusions**

Method

- **Scored the three middleware technologies against a set of more than 20 technical criteria and multiplied the scores by DSES and DSIL-specific weights to derive an overall grade for each technology as applied in each context (DSES and DSIL)**

- **Assignment of DSES and DSIL-specific weights to each criterion (eg, non real-time capabilities important for DSES, not as important for DSIL)**

- **"Raw" scores developed relative to each criterion for each of the three technologies**
  - Drawn from a "pool" of 100 points for each criterion and distributed among the three technologies relative to how well each performs relative to the others
  - Some raw scores based on quantitative data (e.g., latency); others based on presence or absence of certain capabilities (e.g., synchronization); others based on team consensus of the relative strengths and weaknesses of the candidates

- **Weighted grades for each technology, for each application were developed for each criterion, along with on overall score for each technology for each application**

Evaluation Criteria Categories

Candidates evaluated against 26 criteria in the following categories:

- User operations
- Time response
- Architectural robustness
- Performance
- Efficient resource utilization

Evaluation Criteria - User Operations

- **Synchronization -** Ability to facilitate a coordinated, consistent initialization of common simulation parameters and maintain causality (accurate representation of cause and effect/ stimulus and response relationships among the set of executing interoperable simulations)
- **Compile time data checks -** Ability to detect data type inconsistencies early on during development instead of later during simulation testing.
- **Save and restore -** Ability to save the state of a simulation, and at a later time restart this simulation from that time with identical states.
- **Data reduction/analysis -** Tools/capabilities/features for data reduction/analysis/reporting.
- **Data viewers -** Tools/capabilities/features for visualization of run results and run replays.
- **Flexible data exchange -** Flexibility to allow system-to-system data transfer using Cx-defined standards/protocols (e.g., via C3I specification) or other data exchange mechanism or protocols.
- **Data recording -** Run-time tools/capabilities/features for non-intrusive data recording (and playback) of data.
- **Data filters -** Provide mechanisms to selectively distribute data.

Evaluation Criteria – Time Response

- **Latency -** Latency artifacts associated with application data exchange introduced by the middleware.

- **Throughput -** Artifacts introduced by middleware that limits bandwidth supported by applications

- **Multiple concurrent executions -** Provide for multiple, concurrent simulation executions over the same LAN/WAN communications network

- **Simulation time management -** Ability to coordinate advancement of logical time (and its relationship to real-time) among simulation federates. Provides ability to support time coordination among both real-time and non real-time simulation

Evaluation Criteria – Architectural Robustness

- **Recover from middleware crashes -** Graceful recovery from middleware software faults.

- **Recover from network faults -** Graceful recovery from network faults.

- **Recover from simulation crashes -** Graceful recovery from simulation software faults.

Evaluation Criteria - Performance

- **Hardware-in-the-loop -** Provide for integration / interoperation of HWIL/SWIL system representations, in addition to all digital simulation representations

- **Real-time operations -** Provide for integrated operations in real-time (within limits of HW, SW, and OS)

- **Best effort delivery -** Support both guaranteed delivery (via TCP/IP) and best effort (via UDP) message protocols.

- **Causality and repeatability -** Obtain same results from one simulation run to the next with identical inputs. Causal implies that simulation events are in the same order they would occur in the real world, and that everybody sees events in the same order.

- **Distribution transparency -** Ability to implement Cx-level simulations within physical proximity (eg, same Lab) or optionally distribute at various sites with minimal reconfiguration required

- **Dynamic conceptual models -** Ability to transfer ownership of simulation object dynamics from one application to another during the simulation execution.

- **Multi-media support -** Ability to support transfer of simulation video and voice during execution.

Evaluation Criteria – Efficient Resource Utilization

- **CPU -** CPU utilization requirements of the middleware.
- **Memory -** CPU memory utilization requirements of the middleware.
- **Scalability and extensibility -** The characteristic to readily scale in terms of added simulation objects and additional federates.
- **Execution startup time -** Simulation initialization time.

Criteria Weighting

Performance OBJECTIVES	Technical Performance Criteria	DSES weights	DSIL weights
1.1 Support User OPERATIONS	1.1.1 Provide synchronization	10.0%	7.0%
	1.1.2 Provide compile time data checks	2.0%	2.0%
	1.1.3 Provide save & restore	10.0%	10.0%
	1.1.4 Provide data reduction/analysis tools	1.0%	1.0%
	1.1.5 Provide Data viewers	1.0%	1.0%
	1.1.6 Provide flexible data exchange	1.0%	5.0%
	1.1.7 Provide data recording tools	3.0%	4.0%
	1.1.8 Provide data filters	1.0%	1.0%
1.2 Optimize Time RESPONSE of Architecture	1.2.1 Minimize latency	4.0%	11.0%
	1.2.2 Optimize message throughput	4.0%	6.0%
	1.2.3 Support multiple, concurrent executions	2.0%	2.0%
	1.2.4 Support time management	10.0%	2.0%
1.3 Maximize Architecture ROBUSTNESS	1.3.1 Gracefully recover from middleware crashes	2.0%	2.0%
	1.3.2 Gracefully recover from network faults	1.0%	1.0%
	1.3.3 Gracefully recover from simulation crashes	2.0%	2.0%
1.4 Provide Required User PERFORMANCE	1.4.1 Support HWIL	8.0%	13.0%
	1.4.2 Support Real-time M&S/operations	8.0%	13.0%
	1.4.3 Best Effort Delivery - TCP/UDP	8.0%	2.0%
	1.4.4 Support causal and repeatable M&S	5.0%	2.0%
	1.4.5 Provide distribution transparency	4.0%	2.0%
	1.4.6 Support dynamic conceptual models	6.0%	4.0%
	1.4.7 Provide mutli-media support services	2.0%	2.0%
1.5 Optimize Architecture Resource EFFICIENCY	1.5.1 Optimize Node CPU Utilization	1.0%	1.0%
	1.5.2 Optimize Node CPU Memory Utilization	1.0%	1.0%
	1.5.3 Maximize scalability & extensibility	2.0%	2.0%
	1.5.4 Miminize Archtitecture (federate) start-up time	1.0%	1.0%
		100%	100%

Criteria weights developed by Team's judgment of different degrees of relevance of each criteria to the DSES and DSIL communities

Scoring spreadsheet available to assess sensitivities to different weights

Latency Benchmarks

Benchmark code was implementation of simple publish and subscribe

- Data in milliseconds
- Reliable message delivery
- 1000 samples/payload size
- "1 way"

	HLA				
	Size	Average	Std Dev	Min	Max
Single 4 CPU Machine at JSC	**1**	1.05	0.76	0.58	20.58
	4	1.11	0.76	0.59	20.18
	16	1.24	0.78	0.59	20.82
	64	1.39	0.76	0.59	20.11
	256	1.46	0.7	0.59	20.64
	1024	1.22	0.74	0.62	21.29
	4096	1.38	0.68	0.61	18.33

TENA				
Size	Average	Std Dev	Min	Max
1	0.88	0.22	0.5	1.5
4	0.62	0.22	0.5	2
16	0.6	0.3	0.5	6
64	0.6	0.29	0	5.5
256	0.61	0.27	0.5	5
1024	0.66	0.28	0.5	4.5
4096	0.73	0.31	0.5	5

	HLA				
JSC - MSFC	**1**	15.77	0.84	14.62	32.08
	64	15.77	0.79	14.74	31.49
	4096	17.5	9.04	15.89	171.12

TENA				
1	26.16	15.55	15.5	361
64	16.9	12.94	15.5	252.5
4096	47.17	11.29	32.5	252.5

We did not find significant differences in latency performance between TENA and HLA

Raw Scores

Performance OBJECTIVES	Technical Evaluation Criteria	HLA	TENA	DIS-XML/XMP
		Raw Scores		
1.1 Support User OPERATIONS	1.1.1 Provide synchronization	100.0	0.0	0.0
	1.1.2 Provide compile time data checks	10.0	80.0	10.0
	1.1.3 Provide save & restore	100.0	0.0	0.0
	1.1.4 Provide data reduction/analysis tools	0.0	0.0	0.0
	1.1.5 Provide Data viewers	0.0	0.0	0.0
	1.1.6 Provide flexible data exchange	33.0	33.0	33.0
	1.1.7 Provide data recording tools	0.0	0.0	0.0
	1.1.8 Provide data filters	80.0	20.0	0.0
1.2 Optimize Time RESPONSE of Architecture	1.2.1 Minimize latency	33.0	33.0	33.0
	1.2.2 Optimize message throughput	33.0	33.0	33.0
	1.2.3 Support multiple, concurrent executions	33.0	33.0	33.0
	1.2.4 Support time management	100.0	0.0	0.0
1.3 Maximize Architecture ROBUSTNESS	1.3.1 Gracefully recover from middleware crashes	50.0	50.0	0.0
	1.3.2 Gracefully recover from network faults	0.0	0.0	0.0
	1.3.3 Gracefully recover from simulation crashes	0.0	0.0	0.0
1.4 Provide Required User PERFORMANCE	1.4.1 Support HWIL	45.0	45.0	10.0
	1.4.2 Support Real-time M&S/operations	45.0	45.0	10.0
	1.4.3 Best Effort Delivery - TCP/UDP	60.0	40.0	0.0
	1.4.4 Support causal and repeatable M&S	100.0	0.0	0.0
	1.4.5 Provide distribution transparency	33.0	33.0	33.0
	1.4.6 Support dynamic conceptual models	100.0	0.0	0.0
	1.4.7 Provide mutli-media support services	0.0	100.0	0.0
1.5 Optimize Architecture Resource EFFICIENCY	1.5.1 Optimize Node CPU Utilization	0.0	0.0	0.0
	1.5.2 Optimize Node CPU Memory Utilization	0.0	0.0	0.0
	1.5.3 Maximize scalability & extensibility	40.0	40.0	20.0
	1.5.4 Miminize Archtitecture (federate) start-up time	0.0	0.0	0.0

Weighted Grades

Performance OBJECTIVES	Technical Evaluation Criteria	(Assessment Score) Raw Scores HLA	TENA	DIS-XML/XMP	(SE&I X Weight) = DSES weights	(SE&I-Weighted GRADE) DSES grades HLA	TENA	DIS-XML/XMP	(T&V X Weight) = DSIL weights	(SE&I-Weighted GRADE) DSIL grades HLA	TENA	DIS-XML/XMP
1.1 Support User OPERATIONS	1.1.1 Provide synchronization	100.0	0.0	0.0	10.0%	10.00	0.00	0.00	7.0%	7.00	0.00	0.00
	1.1.2 Provide compile time data checks	10.0	80.0	10.0	2.0%	0.20	1.60	0.20	2.0%	0.20	1.60	0.20
	1.1.3 Provide save & restore	100.0	0.0	0.0	10.0%	10.00	0.00	0.00	10.0%	10.00	0.00	0.00
	1.1.4 Provide data reduction/analysis tools	0.0	0.0	0.0	1.0%	0.00	0.00	0.00	1.0%	0.00	0.00	0.00
	1.1.5 Provide Data viewers	0.0	0.0	0.0	1.0%	0.00	0.00	0.00	1.0%	0.00	0.00	0.00
	1.1.6 Provide flexible data exchange	33.0	33.0	33.0	1.0%	0.33	0.33	0.33	5.0%	1.65	1.65	1.65
	1.1.7 Provide data recording tools	0.0	0.0	0.0	3.0%	0.00	0.00	0.00	4.0%	0.00	0.00	0.00
	1.1.8 Provide data filters	80.0	20.0	0.0	1.0%	0.80	0.20	0.00	1.0%	0.80	0.20	0.00
1.2 Optimize Time RESPONSE of Architecture	1.2.1 Minimize latency	33.0	33.0	33.0	4.0%	1.32	1.32	1.32	11.0%	3.63	3.63	3.63
	1.2.2 Optimize message throughput	33.0	33.0	33.0	4.0%	1.32	1.32	1.32	6.0%	1.98	1.98	1.98
	1.2.3 Support multiple, concurrent executions	33.0	33.0	33.0	2.0%	0.66	0.66	0.66	2.0%	0.66	0.66	0.66
	1.2.4 Support time management	100.0	0.0	0.0	10.0%	10.00	0.00	0.00	2.0%	2.00	0.00	0.00
1.3 Maximize Architecture ROBUSTNESS	1.3.1 Gracefully recover from middleware crashes	50.0	50.0	0.0	2.0%	1.00	1.00	0.00	2.0%	1.00	1.00	0.00
	1.3.2 Gracefully recover from network faults	0.0	0.0	0.0	1.0%	0.00	0.00	0.00	1.0%	0.00	0.00	0.00
	1.3.3 Gracefully recover from simulation crashes	0.0	0.0	0.0	2.0%	0.00	0.00	0.00	2.0%	0.00	0.00	0.00
1.4 Provide Required User PERFORMANCE	1.4.1 Support HWIL	45.0	45.0	10.0	8.0%	3.60	3.60	0.80	13.0%	5.85	5.85	1.30
	1.4.2 Support Real-time M&S/operations	45.0	45.0	10.0	8.0%	3.60	3.60	0.80	13.0%	5.85	5.85	1.30
	1.4.3 Best Effort Delivery - TCP/UDP	60.0	40.0	0.0	8.0%	4.80	3.20	0.00	2.0%	1.20	0.80	0.00
	1.4.4 Support causal and repeatable M&S	100.0	0.0	0.0	5.0%	5.00	0.00	0.00	2.0%	2.00	0.00	0.00
	1.4.5 Provide distribution transparency	33.0	33.0	33.0	4.0%	1.32	1.32	1.32	2.0%	0.66	0.66	0.66
	1.4.6 Support dynamic conceptual models	100.0	0.0	0.0	6.0%	6.00	0.00	0.00	4.0%	4.00	0.00	0.00
	1.4.7 Provide mutli-media support services	0.0	100.0	0.0	2.0%	0.00	2.00	0.00	2.0%	0.00	2.00	0.00
1.5 Optimize Architecture Resource EFFICIENCY	1.5.1 Optimize Node CPU Utilization	0.0	0.0	0.0	1.0%	0.00	0.00	0.00	1.0%	0.00	0.00	0.00
	1.5.2 Optimize Node CPU Memory Utilization	0.0	0.0	0.0	1.0%	0.00	0.00	0.00	1.0%	0.00	0.00	0.00
	1.5.3 Maximize scalability & extensibility	40.0	40.0	20.0	2.0%	0.80	0.80	0.40	2.0%	0.80	0.80	0.40
	1.5.4 Miminize Archtitecture (federate) start-up time	0.0	0.0	0.0	1.0%	0.00	0.00	0.00	1.0%	0.00	0.00	0.00
					100% (100%)	61 HLA Grade	21 TENA Grade	7 DIS Grade	100% (100%)	49 HLA Grade	27 TENA Grade	12 DIS Grade

DSES Subgrades

Grade	HLA	TENA	DIS
OPERATIONS grade	21	2	1
RESPONSE grade	13	3	3
ROBUSTNESS grade	1	1	0
PERFORMANCE grade	24	14	3
EFFICIENCY grade	1	1	0

DSIL Subgrades

Grade	HLA	TENA	DIS
OPERATIONS grade	20	3	2
RESPONSE grade	8	6	6
ROBUSTNESS grade	1	1	0
PERFORMANCE grade	20	15	3
EFFICIENCY grade	1	1	0

Other Considerations

- Timing sensitivity in the DSIL -
  - **Timing and latency issues will be drivers in the DSIL, but these are likely to present fundamental simulation design challenges that cannot be solved simply by selecting a middleware technology**

- Technology Maturity –
  - **HLA is the more mature technology of the three we considered.**

- Vendor Independence –
  - **Both HLA and TENA suffer from a kind of vendor dependence problem.**
    - **HLA implementations from different vendors do not interoperate.**
    - **For TENA,**
      - Vendor independence problem derives from the fact that there is only a single implementation.
      - Furthermore, some aspects of TENA development (e.g., mapping an abstract object model into C++ code) must be done by the TENA office, possibly making them a critical link in the development cycle.

- Middleware migration costs –
  - **Were we to choose some other technology than HLA as the common middleware, we would likely have to justify that choice against the redevelopment costs**